BBC RD 1977/45

RESEARCH DEPARTMENT REPORT

The relationship of v.h.f. car radio reception quality to field strength at 10 metres

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THE BRITISH BROADCASTING CORPORATION December 1977

BBC RD 1977/45
UDC 621.396.62
656.11:
621.317.328

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Summary

The results of practical tests of reception in cars have been used to estimate the field-strength at 10m above ground required for a satisfactory service. They showed considerable receiver-to-receiver variations, with more recent receivers incorporating active interference-limiting circuits showing a marked advantage. The suggested limit for a satisfactory service is 60 dB(μV/m) assuming horizontally polarized transmission. Tests on transmissions with mixed polarization indicated a smaller advantage than previous work.

Issued under the authority of

Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION
December 1977

(RA-169)

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1. Introduction

The v.h.f. f.m. service was originally established assuming fixed aerial installations in the home, and field-strength values of the service are quoted according to measurements made at a height of 10m above ground level (a.g.l.), the internationally agreed standard height.

When the question of the extent of coverage for car-radio reception is considered it is therefore convenient to know how the quality of reception may be related to the field strength at 10m.

In general such investigations are not fundamental for a number of reasons; an important one is that the technical performance of car radio receivers is not constant, although average performance has tended to improve over the last few years. Previous investigations have given a general idea of car radio reception[1] and the extent to which f.m. reception is affected by the polarization of the transmission.[2] The present investigation has attempted to examine the performance of a few currently available car radio receivers under practical conditions on the road with the prime purpose of examining the correlation between quality of reception and the field strength at 10m. The investigation applied to the cases of horizontal polarization and of mixed polarization from the transmitter.

2. Method

2.1. General

The test route,* about 60 km in length, was chosen for the subjective assessments to include urban, suburban and rural sections. The BBC national network transmissions from Wrotham and IBA local radio transmissions from Croydon were received. These are, respectively, horizontally and circularly polarized.

On the basis of field strength survey measurements at 10m a.g.l., supplemented by chart recordings of reception at car aerial height, the route was split into a series of short sections over which the field strength, for the most part, remained within one of the following ranges.**

(a) <48 dBμ, (b) 48 to 54 dBμ, (c) 54 to 60 dBμ, (d) 60 to 66 dBμ, (e) 66 to 72 dBμ, (f) >72 dBμ.

The same sections could not apply to both BBC and IBA transmissions,* the route had to be split differently for each, since the transmitters were not co-sited.

2.2. Vehicle

It is well known that ignition interference suppression of the listener's own vehicle is an important factor in car radio reception, particularly at v.h.f. To have investigated this thoroughly would have entailed an extensive programme of subjective assessments involving an appreciable number of combinations of vehicle and receiver.

As a first stage it was decided to concentrate attention on a single car, which was suppressed in accordance with advice given by the manufacturers of the parts used. Full details of the suppression carried out are given in Appendix I.

The vehicle used for the tests was a Morris Marina Coupé. This car was fitted with aerials at two positions, one on the front near side wing, the other on the rear off-side.

Results obtained from this single vehicle, described in this report, show an enormous variation between the performances of individual receivers so that there seemed little purpose in extending the investigation to include a statistical evaluation of suppression performance in individual cars. The car used was considered to be well suppressed and representative of what could reasonably be expected if standard measures are taken. It will be evident from the results, however, that recent developments in receiver circuit design appear to offer a far more promising solution to the problem of combating ignition interference than costly suppression measures carried out on the listener's own car. Such a solution also has the advantage of reducing the effect of interference from other cars on the road.

2.3. Aerials used and their horizontal directivity

The polar response (or by transmitting-aerial analogy, the horizontal radiation pattern) for both receiving aerials used for the listening tests was measured using the Wrotham and IBA transmissions as the signal sources. These aerials were vertical telescopic steel whips with a maximum length of just over one metre. Only one was extended at any time to avoid any possibility of interaction.

* shown in Fig. 1.

** Present survey reports specify the 48, 54 and 60 dBμ field strength contours.

* For IBA circularly polarized transmissions the ranges refer to the measured horizontally polarized component of field strength.

Vehicle ....
Receiver ....
Aerial position ....
Programme ....

Suppression ....
Type .... Length ....
Programme Material ....

BBC

PART OF ROUTE	GRADE EBU 6pt*	REASONS AND REMARKS
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

* Grade 1 — Imperceptible
Grade 2 — Just perceptible
Grade 3 — Definitely perceptible but not disturbing
Grade 4 — Somewhat objectionable
Grade 5 — Definitely objectionable
Grade 6 — Unusable

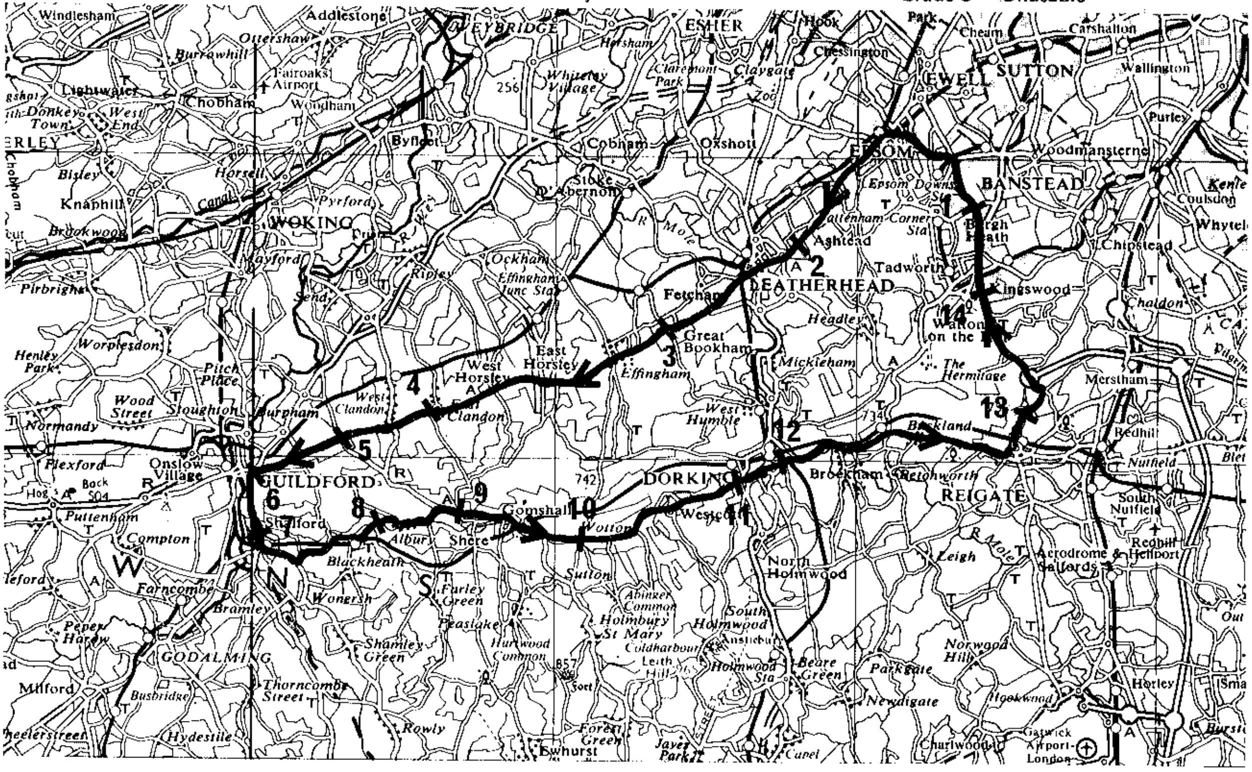

Fig. 1 - Assessment form

Topographical information based upon the Ordnance Survey map with the sanction of the Controller of H.M. Stationery Office "Crown Copyright Reserved"

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A third aerial was tested at this stage, it being thought that this might give somewhat better results. This was a 2m "fibre-glass" whip, mounted on the front near-side and was tested both in the upright position and with the top end bent back and attached to the gutter. However, since this aerial proved no better than the telescopic whips it was not used for the listening tests.

The h.r.p. was deduced by driving the car in a circle in an area where the field strength was relatively uniform. The output from the aerial was plotted on a chart recorder to obtain the output exceeded for 10%, 50% and 90% of the h.r.p.

2.4. Receivers

Five different receivers ranging in cost from £35 to £200 were used for the tests, further details of these are given in Appendix II.

Two of the receivers included a recent development for car radios, namely an active interference limiter circuit; this acts on the output of the f.m. demodulator and is designed to remove impulsive interference spikes, such as those from car ignition systems, from the audio output.

2.5. Listening tests

Listening tests and subjective assessments were carried out by volunteers whilst being driven around the test route. Each volunteer was provided with an assessment form such as is reproduced in Fig. 1* and asked to grade each section individually, using the EBU six-point impairment scale** given in Fig. 1.

Most listener's assessments were influenced by the worst impairment encountered in the section, the grade given being determined by the proportion of time for which this impairment was present and the extent which the worst impairment exceeded the average. The grade considered to represent the subjective impairment for the whole section tended to be that occurring for a small proportion (about 5%–25%) of the route.

The test route was repeatedly traversed to assess the output of the five receivers for both horizontally and mixed polarized transmissions.

A total of 15 observers carried out the listening tests; some of them repeated the route and assessed more than one receiver.

About one half of the assessments were made by observers with a technical background; the remainder were completed by listeners from non-technical areas within BBC Research Department.

* This particular form was for assessment based on transmission from Wrotham. As previously mentioned, different section limits were used for reception of IBA.

** The relationship between this scale and the CCIR five-point impairment scale of Rec. 500 is given by $A_5 = 5{\cdot}8 - 0{\cdot}8A_6$ where A_5 and A_6 refer to the five- and six-point scales respectively.

3. Results

3.1. Horizontal radiation pattern

The details of the h.r.p. measurements are given in Table 1. This shows the conversion factor K which relates output voltage to the field strength. This factor of the aerial and feeder system is the field strength at 1·4m a.g.l. (the height of the mid-point of the aerial) in dBμV/m minus the open circuit input voltage at the receiver. The greater the efficiency of a whip aerial the smaller the K factor.

The optimum length for the steel whip aerials was found to be about 1m.

The average K factor for the steel whips and the fibre-glass whip used in the bent back positions was 12·5 dB for the H.P. transmissions and 8·5 dB (relative to the H.P. component)* for the mixed polarized transmissions.

Comparisons of h.r.p.'s and height gains to chart recordings are made in Appendix III.

The best overall performance is from the front steel whip, and it was this aerial which was used for most of the listening tests.

3.2. Subjective assessments

The results of the 900 subjective assessments taken are given for each receiver separately in the histograms in Figs. 2 to 6. These histograms show the percentage of assessments of Grade 2 or better, Grade 3 or better, and Grade 4 or better for each of the field strength ranges. The grading scale used is shown in Fig. 1.

4. Discussion

4.1. Receiving aerial performances

The important features of the receiving aerial are the mean sensitivity or K factor and the extent by which the sensitivity varies with the bearing.

A radio may be extremely sensitive and give a good signal to noise ratio in areas of low field strength, but its use in a car will be degraded if it cannot handle rapid changes in field strength. This is a reason why portable radios generally do not perform very well as car receivers.

* Note that reference to the horizontally polarized field strength component at 1·4m gives an unduly low K factor for mixed polarized transmissions since the vertically polarized field strength component predominates at low aerial heights.

TABLE 1

K factor of aerial

Frequency MHz and Programme	Percentage of total arc over which aerial pick-up exceeds that for K factor tabulated	Aerial K factor (dB)			
		Steel 1m long		Fibre-glass 2m long	
		Front	Back	Upright	Bent back
89·1 Radio 2	10 50 90	7 12 18	10 13 20	15 19 25	10 12 21
91·3 Radio 3	10 50 90	8 12 18	10 14 23	16 20 26	10 12 16
93·5 Radio 4	10 50 90	10 13 20	10 15 22	18 24 30	8 11 16
95·8 IBA	10 50 90	3 7 11	6 11 21	8 12 17	3 8 14
97·3 IBA	10 50 90	3 8 14	4 10 19	9 14 18	3 8 15

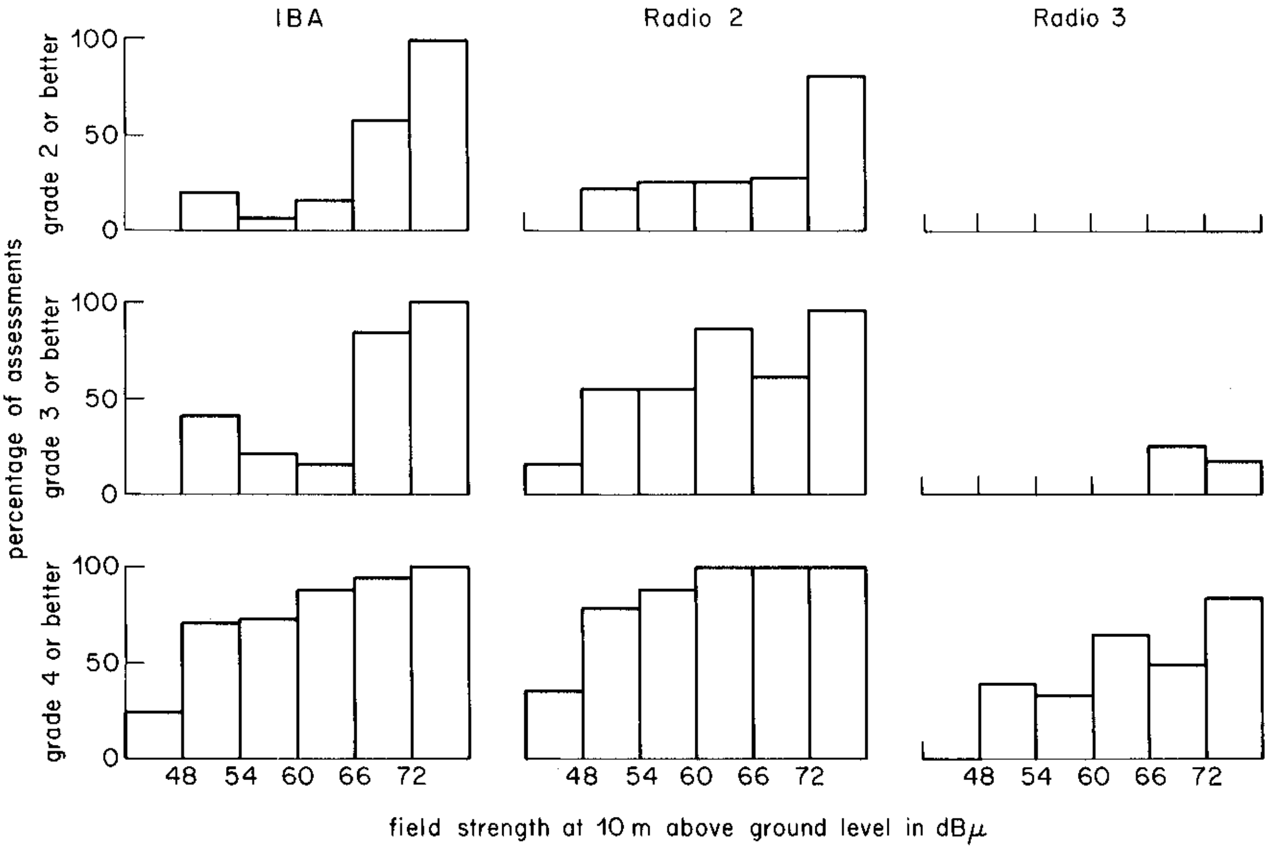

Fig. 2 - Subjective assessment of Receiver A

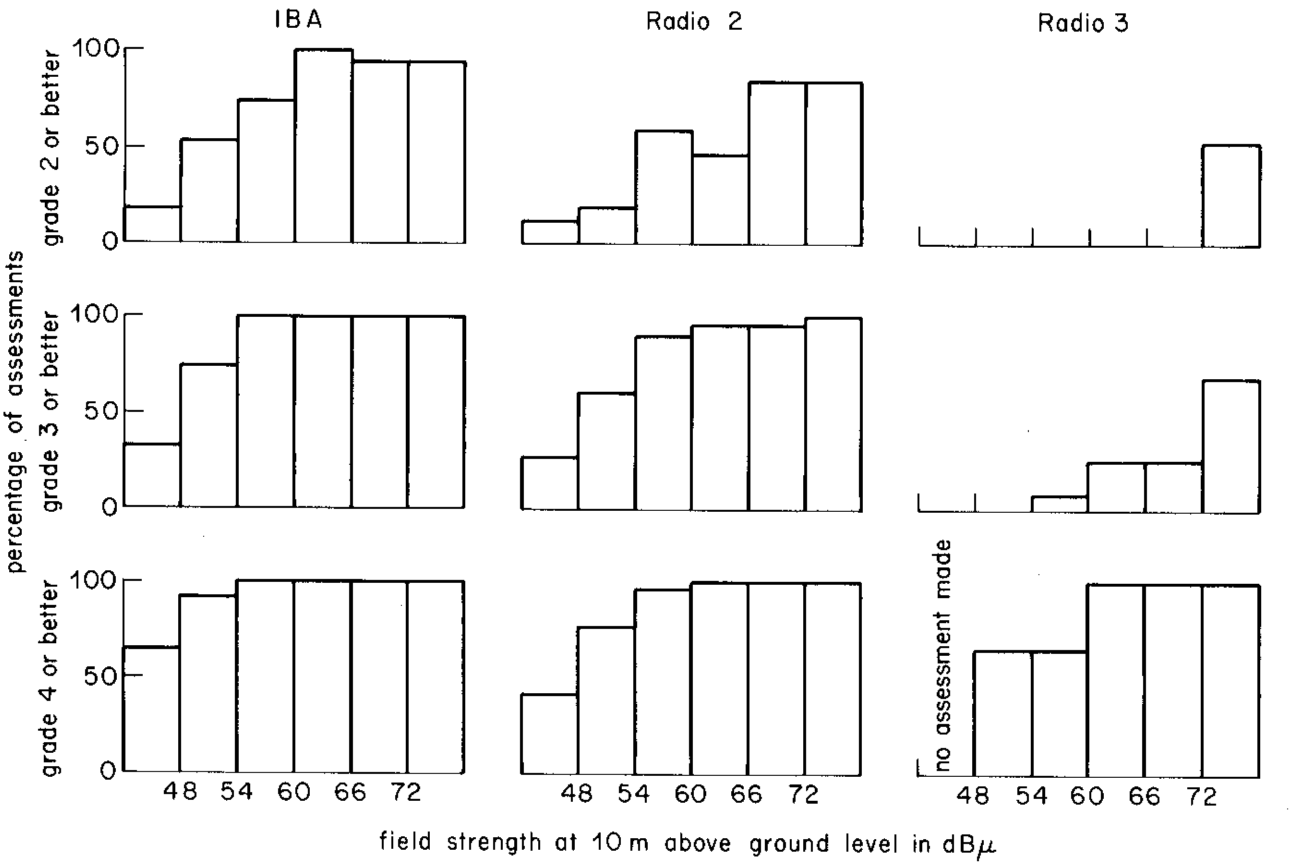

Fig. 3 - Subjective assessment of Receiver B

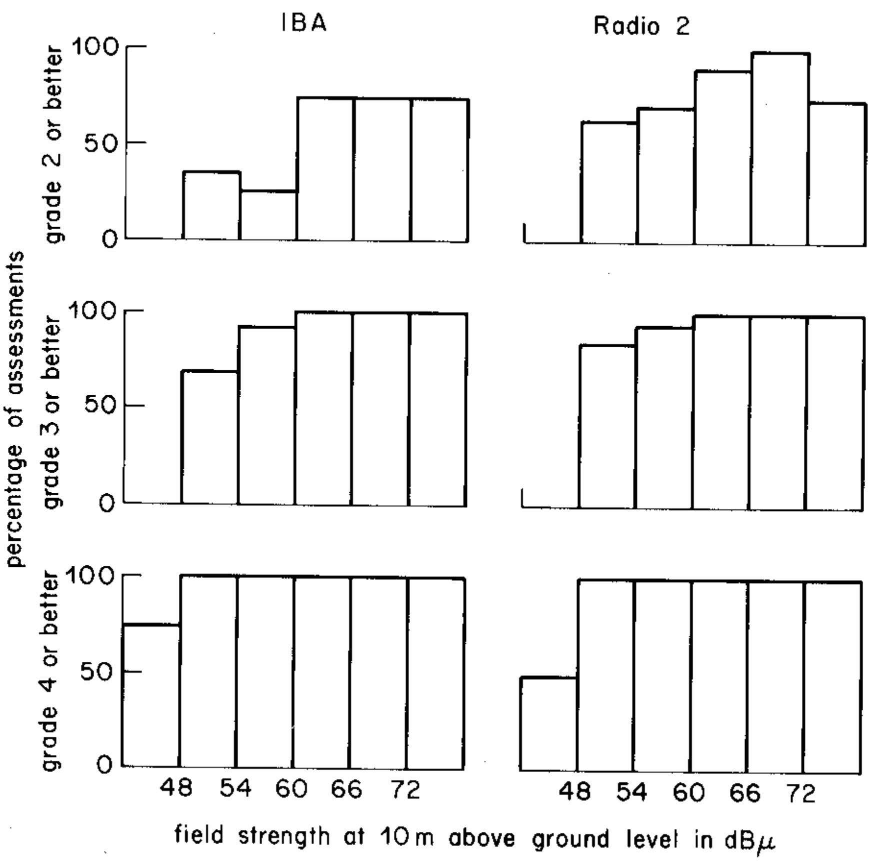

Fig. 4 - Subjective assessment of Receiver C

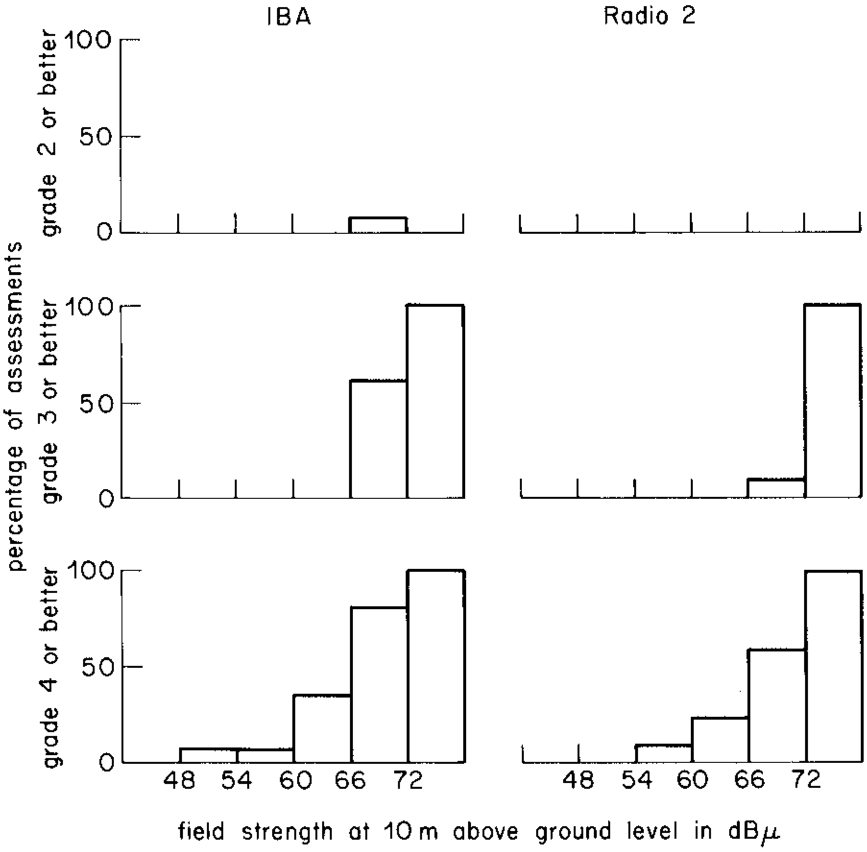

Fig. 5 - Subjective assessment of Receiver D

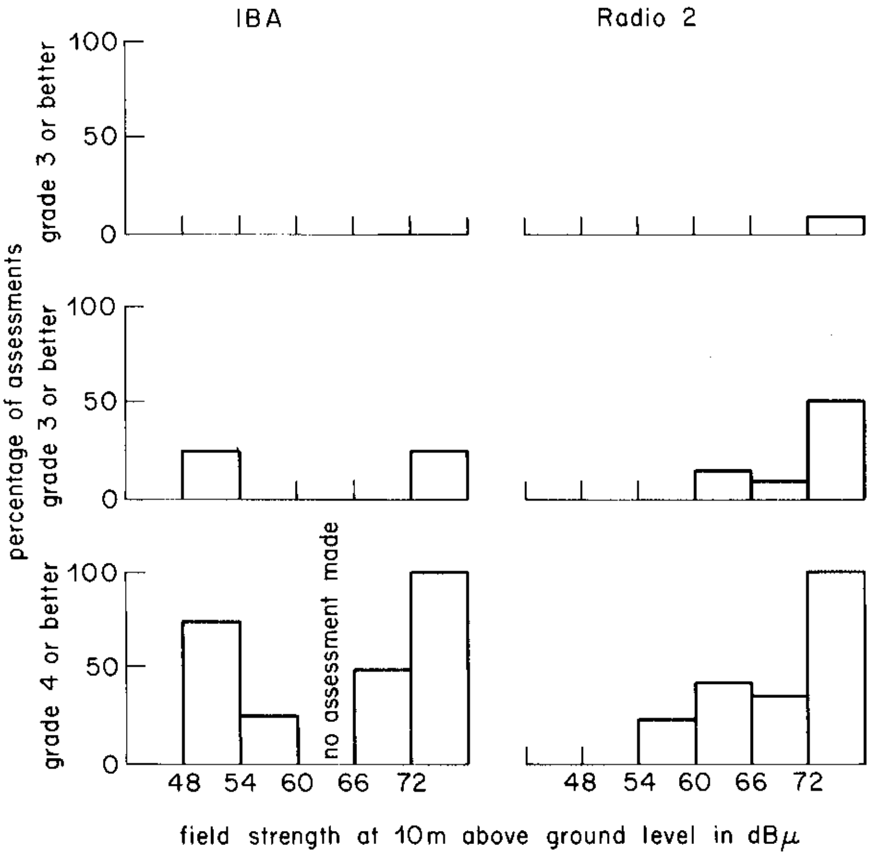

Fig. 6 - Subjective assessment of Receiver E

The mean K factor of 12·5 dB for the horizontally polarized transmissions indicates that the aerial pick-up is slightly greater (by just over 1 dB) as compared with the car aerial used in previous tests,[3] if corrections are made for the different height used as a reference.

The height gains which were derived from information obtained during previous tests[2] are in Fig. 7; this information was used in making a correction of 3·3 dB for the difference between the reference height of 0·9m* used in the previous tests and the 1·4m used in the present report.

The K factor of 8·5 dB for the mixed polarized transmissions is about 1 dB worse than in the previous tests, if corrections are made for the different polarization as well as different height used for the reference.

However, the near omni-directional h.r.p.'s obtained in previous tests[3] for circularly-polarized transmissions were not realized for the transmissions from Croydon, using the Marina car. Nevertheless, for the commonest aerial (front 1m-whip) circular polarization appears to give a useful improvement in the 90%-arc K factor, but the precise amount is not available because the tests could not include both forms of polarization on identical frequencies.

4.2. Subjective assessments

It had been hoped that it would have been possible to combine the results obtained for each radio and programme type to give a single field strength which would represent the limit of service for reception of v.h.f. radio in motor cars, but there was such a large divergence in the subjective performance of the receivers that it was not practical to combine the results. Therefore each receiver was considered separately for the different programmes used.

The programme material on Radio 2 was mainly speech and light music; on Radio 3, chamber music and some classical music; on IBA, either 'pop' music or news programmes.

The histograms show some anomalies; for example the percentage of assessments exceeding a specific grade in some cases decreases with increasing field strength. This is because for some radio programme combinations the sample of assessment was small and results from rural and urban areas were grouped together.**

4.3. Ambient noise levels

The ambient acoustic noise level in a car[4] is such

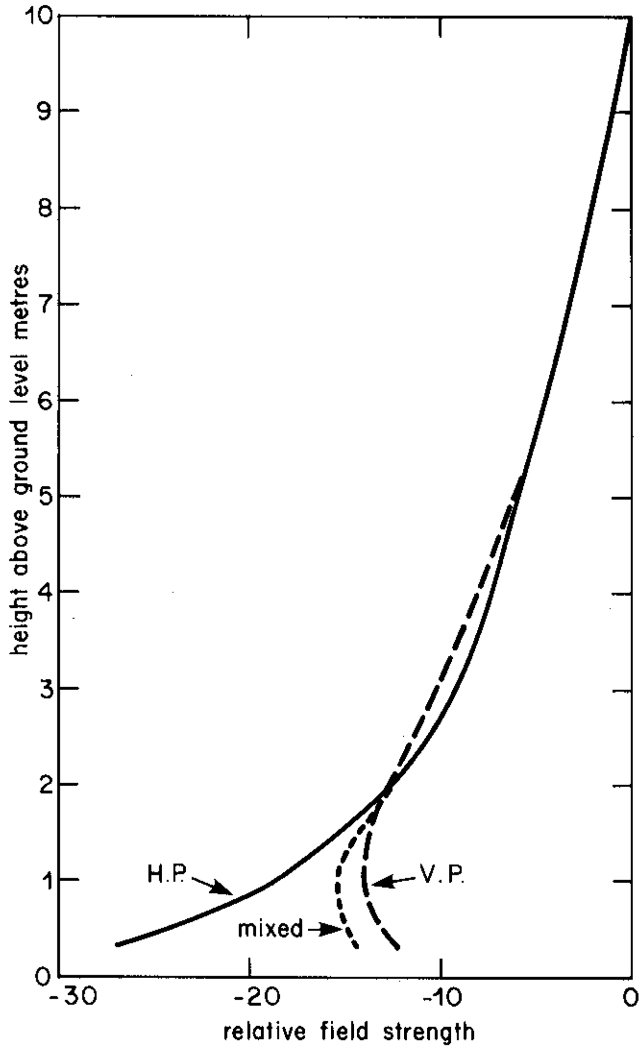

Fig. 7 - V.H.F. Band II, measured field strength variations with height

that, for the average family saloon travelling at 40 to 50 m.p.h., there may be only about 20 dBA difference between the ambient noise level and the loudest at which it is comfortable to listen. (Most motorists would listen below this level).

This high ambient noise level and the distraction of being in a moving motor car made it very difficult to give consistent subjective assessments of interference levels. Because of the adverse conditions the grading tended to be more favourable than if carried out in listening room conditions.

4.4. Limit of service

For the subjective assessments the grade given for a section was the overall assessment for that part of the route. The grade of reception varied over most sections such that the grade at any instant could be at least one grade either side of the overall assessment. Because the listener grading by this method has already adopted a certain amount of averaging, it is appropriate that the

* It is assumed that this reference represented the height of the base of the aerial, considered to comprise a monopole with the car body acting as ground plane.

** Experience indicated that a higher field strength is required in urban areas, due to the greater impulsive interference and standing waves encountered in this environment.

limit of service should be set by a high percentage of assessments. The level decided on is at which greater than 90% of assessments were Grade 3 or better.*

Using the above standard for the limit of service Table 2 below is derived from the histograms.

TABLE 2

Field strength (horizontal component at 10m) for which 90% of the assessments were Grade 3 or better

Receiver	Radio 2	IBA	Radio 3
A	72 dBμ	72 dBμ	72 dBμ (Grade 4)
B	54 dBμ	54 dBμ	60 dBμ (Grade 4)
C	54 dBμ	54 dBμ	Not assessed
D	72 dBμ	72 dBμ	Not assessed
E	72 dBμ (Grade 4)	72 dBμ (Grade 4)	Not assessed

From these results the following limits of service might be considered as appropriate for both H.P. and mixed polarized transmissions:—

i) 54 dBμ for receivers fitted with active interference limiting

ii) 72 dBμ for other receivers

These values apply for all programme types other than those having a large dynamic range, typical of those carried on Radio 3. Mobile reception of such programmes is generally unsatisfactory, since the high dynamic range, associated with the high ambient noise level in a moving car, requires frequent adjustment of the volume control. It is therefore inappropriate to try to specify a minimum field strength required for reception of programmes of this type.

For Radio 3 it was found that the results for the two receivers tested showed a large difference between the percentage of assessments at Grade 4 and Grade 3, this may be explained in the following way:—

(a) For receiver A (without active interference limiting), the higher volume control setting needed resulted in the impulsive interference generated by the test car, (which was induced into the radio either on its supply lead or directly through the case and hence was independent of field strength), being heard at Grade 4. It is possible that this level could have been reduced but as reasonable care had already been taken in suppression no extra attempt was made.

(b) For receiver B (with active interference limiting) the degradation was due to the changing level of field strength which caused 'drop-outs' when driving along.

The chart recording shows that irrespective of the average field strength, the output of the aerial when mobile is frequently liable to very rapid changes of 15 dB, presumably caused by standing wave patterns or sharp minima and nulls in the h.r.p.

These changes cause a certain amount of disturbance on the audio output which is largely independent of mean field strength if the receiver remains limited. This interference is heard at the Grade 4 level when the volume is turned up to accommodate the dynamic range on Radio 3. This interference may be either due to multipath reception or the inability of the receiver to handle these rapid changes of input level.

4.5. Mixed polarized transmissions

The general impression gained when listening to transmissions with mixed polarization as compared with h.p. is that the former give much better results; the percentage of favourable assessments at a specific grade and field strength are usually greater for mixed than for horizontally polarized transmissions. The objective results of this test also shows that the results for mixed transmissions are better than for h.p.

However, if it is considered to be the Grade 3 level for 90% of subjective assessments which determines the limit of service, the difference is not great enough to come into a higher field strength range. Consequently the same field strength limit* is recommended for both mixed and h.p. transmissions;

If the route had been split up into different or smaller field strength ranges a lower limit of field strength might have resulted for mixed transmissions, but the scatter obtained in the results indicated that smaller ranges were not justified. The 6 dB field strength intervals were chosen to coincide with the contours given in v.h.f. radio survey report.

This does not imply that there is no benefit in using

* The corresponding standard currently used for u.h.f. television planning is for 70% of assessments to be Grade 3 or better.

* related to the use of an appropriate receiving aerial in the case of mixed polarization.

mixed polarization; this still has the effect of reducing the extent of periods of unacceptable impairment. However, from previous studies[3] it could be expected that vertical polarization would also achieve this benefit and with a lower transmitter power. It might be appropriate to carry out further tests to ascertain the reasons why the near omni-directional receiving aerial characteristics found in the previous tests[3] were not achieved for the Croydon transmissions.

4.6. Receiver performance

The large divergence in the subjective performance of receivers of similar sensitivity merits further investigation to find the cause of this behaviour. This work might be considered in co-operation with the receiver industry. It probably involves extensive bench testing and simulation of the rapid variations in field strength with multi-path reception encountered in car reception.

5. Conclusions

Broadcasting policy has generally been to base planning standards upon what can reasonably be achieved using present technology, provided this is not unduly costly for the listener or viewer.

If therefore a single standard is to be proposed for v.h.f. car radio reception, it seems reasonable to take account of the advantage obtainable from active interference limiting. The tests described here indicate that such a limit could be set as low as 54 dBμ. However, the grading under the adverse conditions in the car tended to be more favourable than might be expected from long term users in their own cars.

It is therefore suggested that a limit of 60 dBμ at 10m be used for horizontally polarized transmissions or, as a provisional figure, 57 dBμ if related to the horizontally polarized component of mixed polarized transmissions. The latter figure corresponds to a similar range from the transmitter for a given total e.r.p; in other words it does not reflect the advantage found in the previous tests for mixed polarization because the present tests suggest that the advantage is not reliably obtained in practical conditions. No reasonable limit can be recommended for mobile reception of programmes transmitted with very great dynamic range. The dynamic range on all services was found at times to be greater than could be used in a motor car.

The results summarized in Table 2 clearly indicate that some of the receivers tested required very much higher field strengths than those advocated above. Furthermore, these results were based on a single vehicle on which reasonable care had been taken in ignition suppression. A representative sample of cars would doubtless have produced cases requiring even higher field strengths.

In the future the main hope for the wide spread acceptance of v.h.f. car radios depends upon the incorporation of the active interference limiter circuits. It is believed that the use of such circuits may alleviate the need for many of the extra suppression measures normally associated with v.h.f. radios; the extra receiver cost would then be more than offset by the reduced cost of installation.

Further work might usefully be done to establish:—

(a) why the advantage of mixed polarization is apparently less than indicated by previous work

(b) minimum field strength requirements in dense urban areas.

6. References

1. REED, C.R.G., SPENCER, J.G. 1969. Car radio reception tests Winter 1968/9. BBC Research Department Report No. 1969/51.

2. SPENCER, J.G. 1970. Band II f.m. Sound Broadcasting: Field Tests at Radio Nottingham using mixed polarization. BBC Research Department Report No. 1970/35.

3. SPENCER, J.G. 1969. Band II f.m. Sound Broadcasting: the effects of a change to circular polarization. BBC Research Department Report No. 1969/7.

4. ADAC Motorwelt 10/1974.

APPENDIX I

Suppression parts used for Morris Marina

All parts were supplied by the Lucas Electrical Co. Ltd.

Spark plugs	Wire wound resistors in screened plug caps. Part No. 544 219 64.
Distributor cap	Wire wound resistors at the end of all H.T. leads. Part No. 544 214 41.
Alternator	3μF capacitor. Part No. 542 002 97.
Ignition coil	1μF capacitor. Part No. 78 139.
Instrument voltage stabilizer	Two r.f. inductors.
Receiver supply lead	r.f. inductors.
Heater fan	1μH r.f. inductors supplied but not fitted because the fan was not used during the tests.

APPENDIX II

Receivers

Designation	Active interference limiting	Wave bands	Stereo	Pre-set tuning	Tone control
A	No, but now available as optional extra	v.h.f. l.w. m.w.	No	No	Top cut button
B	Yes	v.h.f. m.w.	No	No	No
C	Yes	v.h.f. l.w. m.w.	Yes ①	Yes	Yes
D	No	v.h.f. m.w.	Yes ①	Yes	Yes
E	No	v.h.f. m.w.	No	Yes	Yes

Note ① : Stereo inhibit switch fitted.

APPENDIX III

Comparison of height gains and h.r.p.'s to chart recordings

The chart recordings taken around the route were analysed to give the car aerial output voltage exceeded for 50% of time* for each section of the route.

The ratio of the median field strength for each section measured at 10m a.g.l. with a horizontal aerial to the aerial output voltage levels was obtained.

The mean of this ratio for all sections for the h.p. transmissions was 27 dB for 50% time; for the mixed polarized transmissions the figure was 20 dB for 50% time.

The ratio of the field strength in dBμ at 10m a.g.l. to the aerial output for 50% of time should be equal to the average height gain (1·4 to 10m) + K factor for 50% of h.r.p. arc, and assuming average height gain as indicated in Fig. 7, for h.p. this is

$$16 + 12{\cdot}5 = 28{\cdot}5 \text{ dB}$$

The measured value was 27 dB.

* For the purpose of these tests it was considered more appropriate to relate field strength to time rather than location; moreover this simplified the instrumentation.

A similar sum can be done for mixed polarized transmissions if the height gain conversions from h.p. are taken from Fig. 7.

K factor 50% of h.r.p. arc = 8·5 dB relative to the h.p. field at 1·4m a.g.l.

K factor 50% of h.r.p. arc = 10 dB relative to the mixed field at 1·4m a.g.l.

average height gain (1·4 to 10m) mixed polarization = 14·5 dB

K factor + height gain = 24·5 dB

The measured value was 20 dB relative to the h.p. field which is equal to 23 dB relative to the mixed field at 10m a.g.l.

These measured values are therefore all slightly better than expected.

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